

**DESIGN AND TESTING  
OF A ONE-THIRD SCALE  
SOYUZ TM DESCENT MODULE**

**SPARTAN CONVERSION PROJECT  
SUPER LOKI INSTRUMENTATION**

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**Abstract**

The 1992-1993 senior Aerospace Engineering Design class continued work on the post landing configurations for the Assured Crew Return Vehicle. The Assured Crew Return Vehicle will be permanently docked to the space station fulfilling NASA's commitment of Assured Crew Return Capability in the event of an accident or illness aboard the space station. The objective of the project was to give the Assured Crew Return Vehicle Project Office data to feed into their feasibility studies. Three design teams were given the task of developing models with dynamically and geometrically scaled characteristics. Groups one and two combined efforts to design a one-third scale model of the Russian Soyuz TM Descent Module, and an on-board flotation system. This model was designed to determine the flotation characteristics and test the effects of a rigid flotation and orientation system. Group three designed a portable water wave test facility to be located on campus. Because of additional funding from Thiokol Corporation, testing of the Soyuz model and flotation systems took place at the Offshore Technology Research Center. Universities Space Research Association has been studying the use of small expendable launch vehicles for missions which cost less than 200 million dollars. The Crusader2B, which consists of the original Spartan first and second stage with an additional Spartan second stage and the Minuteman III upper stage, is being considered for this task. University of Central Florida project accomplishments include an analysis of launch techniques, a modeling technique to determine flight characteristics, and input into the redesign of an existing mobile rail launch platform.

**Introduction**

For years, America's journey into space has demonstrated the benefits associated with working in the unique

environment of microgravity. Continuing in this tradition, an ambitious and far reaching program to further the advancement of space technology has been launched. With the space station, the United States enters an era marked by a permanent presence in space. The space station allows continuous rather than intermittent operations to be conducted in orbit. The space station opens doors to many new methods of research and experimentation. Included are better opportunities to observe the Earth and forecast future trends from a vantage point only partially exploited by previous space shuttle missions.

The space station will have a crew of four. The crew will be rotated and resupplied by flights of a space shuttle at intervals of three months. Because of the isolation and potentially hazardous conditions involved in space operations, NASA is committed to the policy of Assured Crew Return Capability for space station crews in the event (1) a medical emergency occurs and an ill, injured, or deconditioned crewmember must be rapidly transported from the space station to a definitive health care facility on Earth; (2) a space station catastrophe forces a rapid evacuation of the crew from the station; and/or (3) the Space Shuttle Program becomes unavailable, and an orderly evacuation of the crew from the space station becomes necessary.

These events, or Design Reference Missions (DRMs), can be met by a concept known as the Assured Crew Return Vehicle (ACRV). Currently, NASA is considering two classes of ACRVs: water landers and open land landers.

The project objectives detailed in this report were developed in conjunction with the Kennedy Space Center ACRV Project Manager and are focused on requirements for a water landing ACRV and post landing operations. The craft configuration is the Russian Soyuz TM Descent Module. The designs presented are as follows: an engineering test model of the Soyuz TM Descent Module; on-board flotation systems for the Soyuz TM Descent Module; and a water wave test facility. During the fall semester a one-tenth scale was used. At the beginning of

the spring semester Thiokol Corporation funded the project. Therefore, the designs were reconfigured to one-third scale and wave testing was performed at the Offshore Technology Research Center at Texas A & M University in College Station, Texas.

Universities Space Research Association (USRA) has been studying the uses of small expendable launch vehicles (SELV) for missions which cost less than 200 million dollars. To accomplish this task, military hardware would be used which has been phased out due to obsolescence or international treaties. USRA and its associates have identified the Spartan missile and the Minuteman III upper stage, which incorporates the Orbus 7 perigee motor, as possible candidates for meeting this need. "Five companies initial assessments indicate that the conversion of the Spartans is technically feasible. Two of the companies, Teledyne Brown Engineering and Orbital Sciences Corporation, extended their studies and developed preliminary vehicle designs."<sup>1</sup> The Spartan Conversion Project Team has investigated the Teledyne Brown Engineering Crusader2B vehicle configuration. This incorporates the integration of the original Spartan first stage and second stage with an additional Spartan second stage and the Minuteman III upper stage. An analysis of launch methods for the Crusader2B is presented. The launch methods investigated include air, land, and sea. Models to simulate the flight characteristics of the full scale Crusader2B are also presented.

In the fall of 1992, Spaceport Florida Authority (SFA), USRA and Cape Canaveral Air Force Station (CCAFS) selected a mobile rail launch platform as an economical launch method for the Crusader2B. In addition, a launch cost of between .5 to 1.5 million dollars was discussed as a target for this launch facility. To assist in the redesign of the mobile rail launch platform, the Spartan Conversion Project Team instrumented the launch rail of the Super Loki sounding rocket. This instrumentation package will be used to determine the thermal and dynamic stresses on the rail. The design and setup of the instrumentation package is presented.

#### Previous UCF ACRV Projects

The UCF senior-level Mechanical and Aerospace Engineering Design class has been working with the ACRV Project Office at Kennedy Space Center since 1989. During the 1989-1990 academic year, four design considerations and solutions were investigated.

The first consideration was providing crew egress and rescue personnel support subsystems to ensure the safe and rapid removal of an ill or injured crewmember from the ACRV by recovery personnel. An Emergency Egress Couch was designed to medically support a sick or injured

crewmember during the ACRV mission. To move the couch from the floor to the hatch, a Four Link Injured Personnel Egress Mechanism (FLIPEM) was developed. The second consideration was the proper orientation, attitude control, and stabilization systems required for the ACRV in the marine environment. Post landing orientation of the ACRV is achieved through the use of three CO<sub>2</sub> charged balloons similar to those used during the Apollo program. Attitude control systems were designed that deploy three multichambered ring segments and an appurtenance to act as a platform for the rescue personnel. Multiple underwater parachute assemblies were designed to provide motion reduction.

The third consideration dealt with providing full medical support to an ill, injured, or deconditioned crewmember aboard the ACRV from the time of separation from the space station to rescue by recovery forces. Extensive research was performed to select suitable medical support equipment and monitors as required by NASA. Equipment was integrated into unified packages and power requirements were addressed.

The fourth consideration was to provide for the comfort and safety of the entire crew from splashdown to the time of rescue. Design solutions were presented for food, water, waste management, atmosphere, contaminant/odor control, and environmental control systems.<sup>2</sup>

The format for the senior-level design class changed in the 1990-1991 academic year. The design requirement was increased from one semester to two semesters. The students design during the fall semester and build and test during the spring semester. The work continued on post landing operations for the water landing ACRV. The design objectives for this class were to determine the feasibility of the previously developed egress and stabilization systems for deployment on the ACRV. Four design teams were formed.

The first team designed, built, and tested a one-fifth scale model of the Apollo Command Module Derivative (ACMD) to be used as a test platform for the egress and stabilization systems. Test results indicated small deviations from the size and weight specifications provided by Rockwell International. Hardpoint accommodations and seal integrity were maintained throughout the water testing.

The second team worked during the fall semester investigating water test facility locations, as well as establishing designs for a permanent facility at the University of Central Florida. As a result of this investigation, stabilization testing with the ACRV model was performed at the O. H. Hinsdale Wave Research Laboratory (WRL) at Oregon State University in Corvallis, Oregon.

The third team designed, built, and tested a one-fifth scale working model of the FLIPEM optimized in the previous academic year as well as a Two Slider Support Mechanism (TSSM) for egressing the couch out the hatch. Testing was conducted in the areas of lifting force with nominal and off-

nominal loads, vertical and horizontal travel distances, redundancy characteristics of the FLIPEM and extension force, travel distance and redundancy characteristics of the TSSM. Test results indicate the design specifications for both systems were met or exceeded without interference to other systems.

The fourth team's objective was to determine, through modeling, the feasibility of reducing heave, surge, and pitch motions of the ACRV model in water using an underwater parachute system. Therefore, one-fifth scale models of the attitude ring and underwater parachute stabilization system, optimized during the previous year, were designed, built and tested. Wave testing, in simulated sea states 2 to 4, at the O. H. Hinsdale WRL, yielded results that indicate that the six-attitude sphere configuration produced minimal stabilizing effects on the ACRV model. The spheres, however, did have the effect of enhancing the flotation characteristics of the model. Numerous parachute arrangements, including single and multiple chutes per cable, increasing the weight attached, using stiff and elastic cables, and devices to partially and totally open the chutes, were tested. Results indicate that the parachutes did affect the motions induced on the model, but did not reduce or increase the frequencies out of the range that causes seasickness.<sup>3</sup>

A concept employing Rocker Stoppers was built and tested at the water test facility to determine the effect a rigid system would have on reducing the oscillations. Two Rocker Stoppers were connected, nose-to-nose, at one end of a long threaded rod. The other end of the rod was connected to a metal plate attached to the model above the break line. Four of these arrangements were connected to the model. Since the Rocker Stoppers are made of rigid plastic, they perform the same work on the upstroke as on the downstroke. This configuration was tested in a simulated sea state 4 (1.2 ft wave height, 0.45 Hz) and the response compared with that from the clean model in the same sea state. The results indicate that a rigid system in this configuration reduces the heave amplitude the model experiences.

The design projects for the 1991-1992 academic year include designs of the ACMD, the Station Crew Return Alternative Module (SCRAM) and the Emergency Egress Couch (EEC). Two teams worked on the ACMD. The first team developed a one-fifth scale model to be used as an engineering test model and test bed. The model design was similar to the 1990-1991 ACMD model, but improved the concept with a radial adjustable center of gravity (CG) and moment of inertia (MI) system. The second team designed a one-fifth scale flotation and attitude system for the ACMD. The flotation system was designed with a segmented ring constructed out of woven nylon fabric coated with butyl rubber. The attitude system provides support to the EEC and consists of a telescoping beam configuration.

The third team designed, built, and tested a one-fifth scale model of the Station Crew Return Alternative Module (SCRAM). The SCRAM consists of a cylindrical crew compartment with a conical shaped heat shield. The heat shield can either be open or closed to the water environment. The weight, CG and MI were modeled using the Adjustable Rotating Weight System. A lift attachment point system was mounted to the lid of the model. Pretests were performed to verify geometric and dynamic similitude. Wave tests took place at the Offshore Technology Research Center at Texas A & M University. Tests were completed in three wave states to determine the SCRAM's flotation characteristics as well as various methods of vehicle recovery. The test results provide the flotation and lifting characteristics of the SCRAM configuration.

The fourth team designed, built and tested a full scale model of the Emergency Egress Couch (EEC). The EEC model consisted of two basic litters, one human weight system, one medical weight system, three layers with flotation, two sets of lift attachment points and a cover. Pretesting and flotation testing were performed on the UCF campus. The dynamic testing was performed at Patrick Air Force Base with the Department of Defense Manager Space Transportation System Contingency Support Office, and the 41st Air Rescue Squadron (ARS). The test results and input from the 41st ARS provided geometric and dynamic parameters to be used in further designs of the EEC.<sup>5</sup>

#### **1992-1993 ACRV Design Projects**

During 1992 the Russian Space Agency, NPO Energia, suggested the Soyuz TM Module to NASA for use as the Assured Crew Return Vehicle from the space station. Two areas of interest identified were the flotation characteristics of the Soyuz TM Descent Module, and the stabilization characteristics of a rigidly mounted flotation system.

USRA is determining the feasibility of using obsolete military hardware to assemble and launch a Small Expendable Launch Vehicle (SELV) capable of placing a 250 to 350 pound payload into Low Earth Orbit (LEO) for under 200 million dollars. To assist with this determination, a Crusader2B configuration was used and three tasks were defined: 1) launch methods; 2) flight characteristics; and 3) stresses occurring during a mobile rail launch. Four design teams were formed and tasked as follows:

##### **Team #1-Soyuz Model**

The Soyuz Model Team was to use geometric and dynamic constraints to design, build and test a one-tenth scale working model of the Soyuz TM Descent Module. The model was required to incorporate a rigidly mounted flotation and orientation system.

### Team #2-Soyuz Flotation & Orientation Model

The objective of the Soyuz Flotation and Orientation Model Team was to design, build, and test a one-tenth scale model of a flotation and orientation system for the Soyuz TM Descent Module. The team was to address location, storage, and deployment.

### Team #3-Wave Test Facility

The Wave Test Facility Team was to design, build and operate a wave test channel for testing the one-tenth scale Soyuz TM Descent Module Model (SDMM). The waves were to accurately simulate the sea conditions which the ACRV may encounter. The team was to investigate the mechanics of the facility, the control system, and the data acquisition system and equipment necessary to perform the required analysis on the Soyuz TM Descent Module model.

### Team #4-Spartan Conversion Project

The Spartan Conversion Project Team was given two tasks during the fall semester: 1) investigate various launch techniques for the Crusader2B; and 2) model the flight characteristics of the full scale Crusader2B. During the spring semester, the team was to determine the dynamic and thermal stresses of a Super Loki sounding rocket mobile launch rail platform.

The ACRV projects changed direction for the Spring semester. Thiokol Corporation funded the building and wave testing of the Soyuz TM Descent Module Model. The Spring tasks were to: 1) build a one-third scale model; 2) build on-board flotation systems; 3) test at the Offshore Technology Research Center (OTRC); and 4) assist Thiokol with proprietary testing. The wave test facility at UCF was not built or operated.

A one-third scale was used both geometrically and dynamically for all ACRV models. To accomplish this a Buckingham Pi dimensional analysis was performed and the Froude scaling factors were determined. These factors allow the model to accurately simulate the characteristics of the full scale craft. While the geometric dimensions of the craft scaled directly by one-third, other parameters, including volume, weight, and mass moment of inertia scaled by powers of one-third.

## 1992-1993 Soyuz TM Descent Module Design, Building, and Testing Results

### Soyuz TM Descent Module Model

The Soyuz Model Team designed a one-third scale model of the Soyuz TM Descent Module (SDM). Current data for the geometric and dynamic constraints of the Soyuz were supplied by NPO Energia through NASA/KSC and NASA/JSC. The two areas researched were construction of the model shell and a center of gravity (CG) and mass moment of inertia (MI) system.

The crew compartment and the heat shield are constructed out of 3/8 inch thick fiberglass. The heat shield is reinforced with six wood stringers glassed to the structure in a spoke configuration. The circular access hatch of the model shell is 3/8" plate aluminum. The heat shield is fastened to the crew compartment by 16 symmetrically placed bolts. Eight symmetrically placed bolts attach the access hatch. The joints are sealed with a silicone based seal. Washers and T-nuts are used on all bolt assemblies (Figure 1).

The weight, MI, and CG were placed with an adjustable multi-axial weight system. The weight system consists of a rectangular frame, all-thread and lead weights. The outer rectangular frame is constructed of 6061-T6 aluminum. The frame members are chamfered on the ends and TIG welded together at 90 degrees, creating a four-arm system. An aluminum doughnut ring is TIG welded to the bottom of the four-arm system. The flange-ring system is sealed by compression of O-ring gaskets between the doughnut and top section flange, and silicone caulking between the doughnut and bottom section flange. One #8 all-thread screw is bolted through the top and bottom of each member of the four-arm system. Lead weights are used on the threaded rods to supply mass for adjustment of the CG and MI (Figure 2).

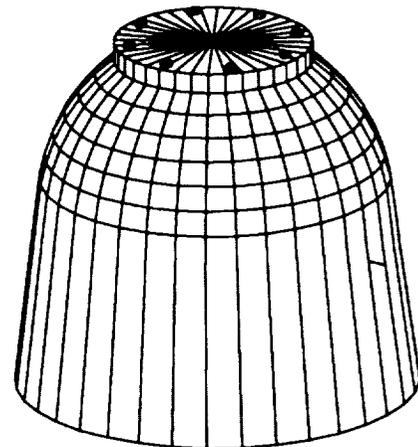


Fig. 1 Soyuz TM Descent Module Model

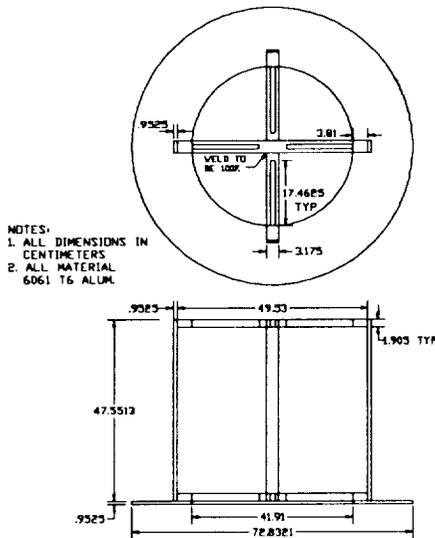


Fig. 2 Adjustable Multi-Axial Weight System

A two phase test plan was developed to evaluate the model. Phase I took place at the UCF Aerospace Senior Design Lab and consisted of a series of pre-tests to confirm the Soyuz model met its specifications. The tests included geometric similitude, model strength, water intrusion, CG and MI similitude, and flotation compatibility. Test results indicate that the model met its geometric and strength constraints. Leakage occurred during the initial testing, therefore silicone was used to supplement all seals. The CG of the model shell and CG/MI system, without the weights, is (26.8,0.0) cm with the origin located at the center point of the bottom of the model. The moments of inertia of the model shell and CG/MI system, without the weights, are  $I_x = 3.42 \text{ kg}\cdot\text{m}^2$ ,  $I_y = 3.55 \text{ kg}\cdot\text{m}^2$  and  $I_z = 3.62 \text{ kg}\cdot\text{m}^2$ . Using lead weights, the CG of the full scale Soyuz was modeled to within 5%, and the moments of inertia to within 28%. The flotation system integrated successfully with the model. The MI modeling could have been improved if a lighter model shell were used.

Phase II took place at the OTRC. Tests were completed to determine the Soyuz's flotation characteristics. This testing involved tethered and untethered testing of the model as well as a number of changes to the wave environment. Sea state conditions were set during the development of the model. Five wave states were modeled and evaluated (Table 1). The test results provide the flotation characteristics of the Soyuz configuration. Observations derived from the test results were also provided to the ACRV Program. These observations were: (1) the frequency of regular wave state three was approximately equal to the natural frequency of the tethered Soyuz model. Therefore, every second wave in the tethered tests damped the pitching motion of the craft.

In the untethered test, the model exhibited an oscillating rolling motion; and (2) the model in regular sea state four exhibited a significant increase in pitch in the tethered test. During the untethered test, the craft oriented itself hatch away from the on-coming waves and tracked straight in the wave direction.

Table 1 Wave States Tested

Sea State	Average Period	Average Wave Height
Regular 3	2.802 s	0.837 m
Regular 4	4.908 s	1.823 m
Random 1	1.81 s	0.2236 m
Random 2	3.073 s	0.6273 m
Random 3	4.289 s	1.328 m

### Soyuz Flotation & Orientation Model

The Soyuz Flotation & Orientation Model Team designed one-third scale on-board flotation and orientation systems for the SDM. The systems form a rigid body with the SDM after deployment. Areas considered during design included: (1) required buoyancy; (2) means of rigid attachment; (3) work platform for rescue personnel; (4) feasibility for full scale Soyuz; and (5) a method of orientation.

Two flotation systems were designed and built. The four main features of the Umbrella Arm design are the locating collar, support tubes, flotation devices and the stabilization bag. The collar is made of slip rolled 6061-T6 aluminum flat stock and rigidly attaches the flotation system to the SDMM. Three studs are welded on to the collar to facilitate fastening of the support tubes. The collar is placed over the neck of the SDMM and clamped down with a bolt. This bolt tightens the collar to the SDMM. The collar is kept from rotating or slipping by installing four bolts through tapped holes and securing them with nuts. Two nut and bolt assemblies attach the support tubes onto each collar stud. Each support tube is mounted to a flotation attachment plate with a nut and bolt assembly. Using four Velcro strips an inflatable bag is attached to each attachment plate (Figure 3).

The Modular Inflatable design consists of five square inflatable bags positioned in the form of a pentagon along the water line of the SDMM. The square inflatable bags for each system are constructed of an outer layer of awning canvas with an inner plastic bladder (Figure 4).

On the SDM, either of these systems could be deflated, and stored in recessed compartments in the outer shell of the capsule. After splashdown, the system would deploy and inflate to provide stability. Each of these systems provides flotation, orientation, and a working surface for the rescue crew members.

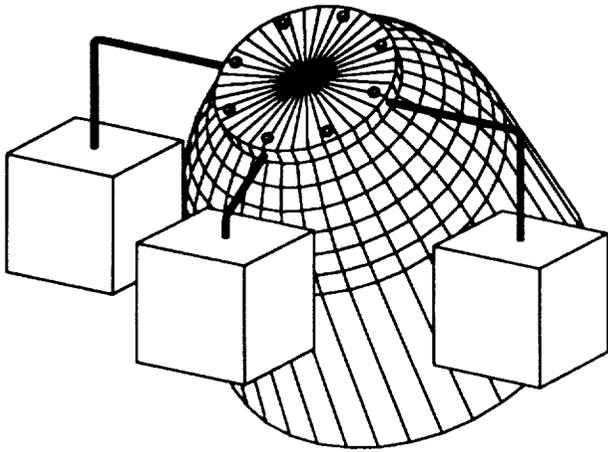


Fig. 3 Umbrella Arm Flotation System

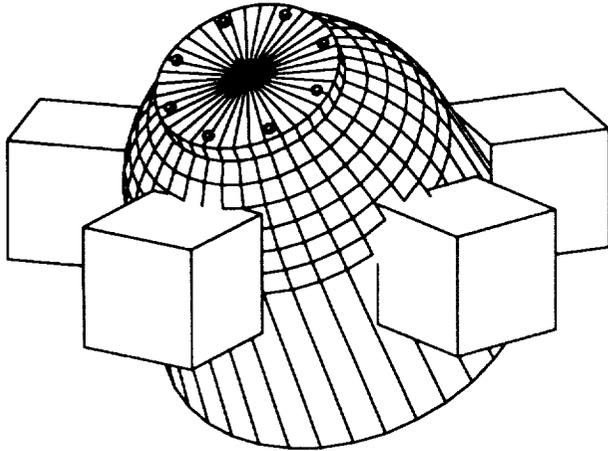


Fig. 4 Modular Inflatable Flotation System

A two phase test plan was developed to evaluate the model. Phase I took place at the UCF Aerospace Senior Design Lab and consisted of a series of pre-tests to confirm the flotation & orientation model met its specifications. The tests included safety, required buoyancy, water intrusion, dimensional verification, Velcro strength, rigid attachment, and weight verification. Test results indicate that the models were safe to use. The provided buoyancy met its specification and was sufficient to support the model. Water intrusion into the inflatable bags was negligible and did not affect the dynamic flotation characteristics. The models met their dimensional and weight constraints. Velcro strength was sufficient to resist the force of the wave motion, and each system attached rigidly to the Soyuz model.

Phase II took place at the OTRC. Tests were completed to determine the flotation characteristics of the SDMM with the Umbrella Arm system attached. This testing involved tethered tests and a number of changes to the wave environment. Sea state conditions were set during the development of the model. Three wave states were modeled and evaluated. The first was a regular sea state three with a 0.837 meter wave height and a 2.802 second period. The second was a regular sea state four with a wave height of 1.823 meters and a period of 4.908 seconds. The third wave state was a random sea state two with an average wave height of 0.6273 meters and an average significant period of 3.073 seconds. The test results provide the flotation characteristics of the SDMM craft with the Umbrella Arm system deployed. Observations derived from the test results were also provided to the ACRV Program. These observations were: (1) a small increase in the heave motion with a large decrease in the pitch motion; (2) a flotation device which provides stabilization is necessary to extract the crew from the craft; and (3) sea state three bare model pitching motion was normalized.

#### Wave Test Facility

The Wave Test Facility Team designed a facility to test a one-tenth scale Soyuz model. The design parameters which the group considered were: (1) kinematic scaling; (2) bottom effects; (3) portability; (4) water tank; (5) wave generation; (6) wave absorption; and (7) measurement and instrumentation.

The wave tank designed is an above ground wood tank. The rectangular tank is 6.1 meters long, 1.83 meters wide and 0.91 meters deep. The generator section occupies the first 0.4 meters of the tank. A 1.8 meter section, after the generator, is reserved to allow the wave to build to steady state prior to entering the test section. The test section immediately follows the transition section and is approximately 2.1 meters long. This provides for a 3.9 square meter test area and allows for approximately two full wavelengths of scaled regular sea state three. The final section of the wave tank is the wave absorber. This section is approximately 1.7 meters long and consists of four vertical walls of various porosity. Access to the tank is provided by a movable platform (Figure 5).

The tank is divided into five segments. The segments of the tank are composed of pressure treated plywood panels. The plywood side panels are fastened to the single floor panel by four triangular support members. The two end sections of the tank are also constructed of pressure treated plywood panels, and are connected to the sides of the tank with angle steel. The wooden rectangular tank supports the weight of the water but is not watertight. A 0.6 mm thick liner contains the water.

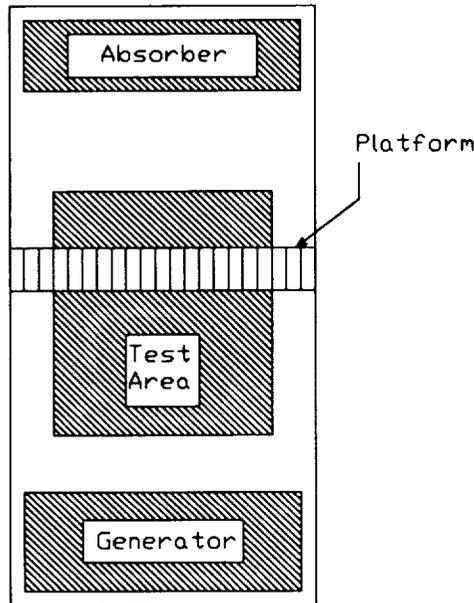


Fig. 5 Wave Test Facility Concept

The wave generator consists of a hinged flap driven by a pneumatic cylinder and linkage. This mechanism is a solid vertical surface which pivots about a mount rigidly attached to the pool bottom. The wave board is actuated by a pneumatic cylinder. The cylinder has a 5.08 cm diameter bore with a 30 cm stroke. The required air pressure for the cylinder is 275.79 kPa. The cylinder is constructed of stainless steel and aluminum. The cylinder is attached to a clevis bracket which is rigidly attached to the framework on the end of the wave tank. The cylinder rod is extended by a linkage which connects it to the top of the generator frame. The linkage consists of series of couplings and threaded rods attached to a ball joint connection located at the top of the frame.

The wave form created by the generator is managed by controlling the air supplied to the cylinder. The direction of the cylinder is controlled by switching the supplied and vented air to the cylinder. A solid state variable time relay is used to control the switching of the solenoid valve and ultimately the period of the waves generated. Stroke limiters are employed to limit the motion of the cylinder rod. The wave characteristics are determined by a fully manual measurement system, while the Soyuz model data is measured with an automatic electronic system.

#### Spartan Conversion Project

The Spartan Conversion Project Team focused on launch configuration alternatives for launching the Crusader2B for under two million dollars. The flight characteristics of the

full scale Crusader2B were also investigated. The launching methods considered were air, land, and sea launch.

Two air launching alternatives considered were the parachute drop, and the wing pylon launch. The parachute drop launch involves deployment of parachutes which pull the rocket out of the back of a large cargo aircraft, then stabilize its attitude with an additional set of parachutes so that the rocket is pointing upward (vertically), releasing the parachutes, and igniting the first stage motor. The wing pylon launch method involves dropping the launch vehicle from the underside of a B52 aircraft and allowing it to freefall. The aircraft veers to the side to fly clear of the launch area. The first stage motor is then ignited and the guidance system steers the rocket into the proper trajectory.

Three land launching configurations were considered. These were above ground launch complexes, existing mobile launchers, and existing abandoned silos. Modifications would need to be made to each of these launch facilities to accommodate the Crusader2B.

The sea launching techniques considered were: (1) barge tower; (2) partially submerged; and (3) fully submerged launch. Using the barge tower system, the launching structure, in the horizontal position, and integrated launch vehicle are towed away from populated areas on the barge. Once the launch site is reached, the launch structure with the integrated vehicle is raised from the horizontal to the vertical launch position and readied on the platform for launch. The support vessel with on-board control room, clean room, and support personnel moves away from the launch platform and tower to a safe location for launch. The launch sequence is then activated. The fire command is not sent until the vehicle roll and pitch rates come into specified tolerances.

The partially submerged launch involves towing the launch vehicle totally submerged, fitted with a dummy tow nosecone, and sealed in a watertight casing. When the launch site is reached, the rocket is oriented to the vertical position using flotation and ballast, exposing approximately ten percent of the rocket, by volume, above the waterline. The dummy tow nosecone is then removed and the payload, stored on-board the support vessel in a clean room, is installed onto the launch vehicle. The support vessel then moves away to a safe location and the launch sequence is started. The fire command is not sent until the vehicle roll and pitch rates come into specified tolerances.

The difference between the partially submerged launch and the fully submerged launch is that instead of flotation being attached to the rocket, the rocket is allowed to settle slightly below the ocean surface. The rocket is then ignited while completely submerged and exits the water with a considerable buoyant force.

The ability to launch for under two million dollars was an important consideration in choosing the launch method of the Crusader2B. Therefore, the parameters of initial cost and operational cost were heavily weighted in the determining

means process. The partially submerged launch method and the modification of an existing mobile launch rail allow for a simple launch method which require few modifications and provide good mobility. This mobility increases launch site selection which increases orbital range selection. The systems are also durable and require fewer range safety restrictions. These attributes lead to an inexpensive, flexible method of launching a SELV into low earth orbit.

The Aerodynamic Model (AM) required that the flight characteristics be the same as those of the full scale Crusader2B. The AMs considered were the flow table, the subsonic wind tunnel, and the supersonic wind tunnel model. These models must produce the same Reynold's number ( $Re$ ), or be able to produce enough data points so that the  $Re$  can be extrapolated. The most important parameter in the selection of the method of aerodynamic testing was the Mach number. If the testing facility is unable to reach the full scale QMAX Mach number, the dynamic similarity between the full scale Crusader2B and the scaled AM is not satisfied. With the importance of the Mach number parameter, the supersonic wind tunnel testing was selected as the optimal solution for the aerodynamic modeling.

In the fall of 1992, Spaceport Florida Authority (SFA), USRA and Cape Canaveral Air Force Station (CCAFS) selected modifying an existing mobile rail launch platform as an economical launch method for the Crusader2B. In addition, a launch cost of between .5 to 1.5 million dollars was discussed as a target for this launch facility. The Spartan Conversion Project Team designed and tested an instrumentation package for a Super Loki sounding rocket launch rail to determine thermal and dynamic stresses on the rail during launch. The Super Loki launch rail (SLLR) is a twelve foot long launch rail of anodized aluminum.

The instrumentation package consists of four sections. The sensor section has two strain gauges and four thermocouples (Figure 6). These sensors are responsible for taking accurate data during the launch of the Super Loki rocket. The second section is the wires that transmit the data from the sensors to the data acquisition devices. The wires that are on the SLLR are resistant to high temperatures. The next section is the data acquisition devices. These devices include a strain indicator which converts the signal from the sensors to data that the micro-loggers record and a data logger which records the required data. The last section in the instrumentation package is the protective coverings. These coverings include the ducts that protect the wiring from data corrupting radio noise, two boxes which protect the amplifiers, and the data loggers (Figure 7).

This package is intended to acquire data on the launch of a Super Loki rocket and the effects of the launch on the rail. This includes the strains imparted on the rail by the driving fins on the dart of the rocket, and the frictional heating imparted to the rail during the launch.

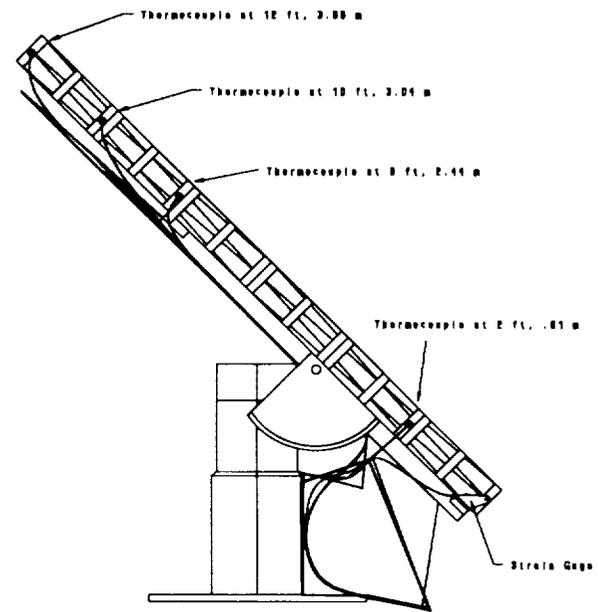


Fig. 6 Instrumented Rail

The project was separated into four phases: design, installation, pre-test, and test. During the design phase an analysis was performed in Algor to determine the location of the stresses the launch rail mounting bracket would experience during a launch. This determined the mounting location of the strain gauges on the launch rail mounting bracket.

The installation phase included the method for mounting the strain gauges and thermocouples on the rail, as well as the method for constructing protective ducts and boxes. The pre-test phase consisted of a series of tests to confirm that the strain gauges, cables, data loggers, and computers perform to specifications and within an acceptable error limit.

During the pre-test phase, tests were done to verify sensor mounting and operation, cable operation, and data logger performance and interface. The results from the tests showed that all sensors were mounted correctly and performed properly. The cables were connected securely and functioned accurately. Data recorded by the data loggers was accurate. These tests also provided data on the magnitude and linearity of the axial and torsional stresses on the mounting bracket. These stresses were found to behave linearly. Torsional stresses were found to be negligible when compared to axial stresses, therefore, the torsional stresses are neglected.

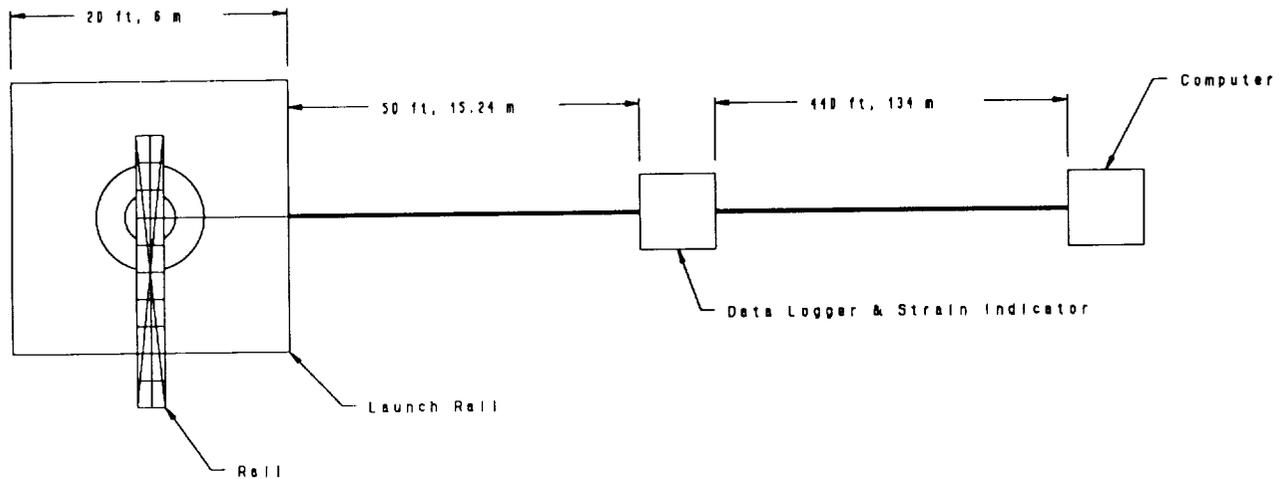


Fig. 7 Final Site Set-Up

Phase III consists of gathering the thermal and dynamic stresses from two real time launches of the Super Loki sounding rocket. These launches will be performed in conjunction with Spaceport Florida Authority at Cape San Blas, Florida. The testing has not been performed at this time.

#### Summary

The 1992-1993 senior Aerospace Engineering Design class completed two projects. The first project was to design, build, and test a SDMM and on-board flotation & orientation systems. The second project was the Spartan Conversion Project which included an instrumentation package for the Super Loki sounding rocket.

The objective of the Soyuz project was to determine the flotation characteristics of the SDM with and without flotation. Construction of the Soyuz model and a center of gravity and mass moment of inertia system were completed. The Flotation & Orientation project completed work in determining: required buoyancy, means of rigid attachment, a work platform for rescue personnel, feasibility for the SDM, and a method of orientation. A wave test facility to test a one-tenth scale SDMM was designed.

The objectives of the Spartan Conversion Project were to investigate various launch techniques for the Crusader2B, model the flight characteristics of the full scale Crusader2B, and provide design input into the modification of an existing mobile rail launch platform. To accomplish these objectives several launch techniques were investigated, modeling methods researched, and theoretical analyses performed on a mobile launch rail bracket

One-third scale models of the SDM and two on-board flotation & orientation systems were designed, built and tested. Testing took place in two phases. The fidelity of the Soyuz model was established from geometric and dynamic characteristic tests performed on the model in Phase I. Results from Phase I tests on the SDMM indicate that the model met its geometric and strength constraints. Leakage into the model was prevented by supplementing the seals with silicone. The center of gravity was modeled to within 5%, and the moments of inertia to within 28%. Integration with the flotation & orientation systems was successful. Phase I testing on the Umbrella Arm system and the Modular Inflatable system indicate that the models were safe to use. The buoyancy provided met specification and was sufficient to support the SDMM. Water intrusion into the inflatable bags was negligible and did not affect the dynamic flotation characteristics. The models met their dimensional and weight constraints. Velcro strength was sufficient to resist the force of the wave motion, and each system attached rigidly to the SDMM.

Phase II testing took place at the OTRC. The facility accommodated all testing configurations and the staff provided excellent support. Tests were completed to determine the SDMM's flotation characteristics with and without the Umbrella Arm system. The testing involved tethered and untethered testing of the models as well as a number of changes to the wave environment.

Five wave states were used to test the bare SDMM. The test results provide the flotation characteristics of the SDM configuration. Observations derived from the test results were provided to the ACRV Program. These observations were: (1) the frequency of regular wave state three was

approximately equal to the natural frequency of the tethered Soyuz model. Therefore, every second wave in the tethered tests damped the pitching motion of the craft. In the untethered test, the model exhibited an oscillating rolling motion. and (2) The model in regular sea state four exhibited a significant increase in pitch in the tethered test. During the untethered test, the craft oriented itself hatch away from the on-coming waves and tracked straight in the wave direction.

Three wave states were modeled and evaluated in the testing of the Umbrella Arm system. The test results provide the flotation characteristics of the SDMM with the Umbrella Arm system deployed. Observations derived from the test results were also provided to the ACRV Program. These observations were as follows: (1) a small increase in the heave motion with a large decrease in the pitch motion, (2) a flotation device which provides stabilization is necessary to extract the crew from the craft, and (3) sea state three bare model pitching motion was normalized.

A wave test facility was designed to test a one-tenth scale SDMM. The design parameters which the group considered were kinematic scaling, bottom effects, portability, water tank, wave generation, wave absorption, and measurement and instrumentation. The facility is designed to be portable. The water tank is constructed of wood in five sections. A 0.6 mm thick liner contains the water. The wave generator consists of a hinged flap driven by a pneumatic cylinder and linkage. A manual measurement system is used to determine and monitor wave motion, while an automatic electronic system is used to retrieve data from the model.

The launching methods considered for the Crusader2B were air, land, and sea launch. Two air launching alternatives were considered: the parachute drop, and the wing pylon launch. Modifications to three existing land launching configurations were considered. These configurations were above ground launch complexes, existing mobile launchers, and abandoned silos. Barge tower launching, partially submerged launching and fully submerged launching were the sea launch configurations considered. The parameters of initial cost and operational cost were heavily weighted in the determining means process. The partially submerged launch method and the modification of an existing mobile launch rail were the methods chosen to fulfill the launching requirements.

Flow table, subsonic wind tunnel, and supersonic wind tunnel modeling were investigated for use in determining the flight characteristics of the Crusader2B. Supersonic modeling was selected due to the ability to match the full scale mach number.

To determine the thermal and dynamic stresses on a mobile launch rail mounting bracket, an instrumentation package was designed and pre-tested. The instrumentation package consists of one data logger, 2 single element strain gauges, four thermocouples, high heat resistant cable, high

temperature thermocouple wire, non-shielded wire, and high temperature resistant aluminum tape.

The mounting location of the strain gauges on the launch rail mounting bracket was determined by performing an Algor analysis. The pre-tests showed that the equipment performed to specifications and within acceptable error limits. These tests also showed that the axial and torsional stresses on the mounting bracket behave linearly. Torsional stresses were found to be negligible when compared to the axial stresses and are neglected. Dynamic testing of the Super Loki sounding rocket has not been performed. Two launches are on the schedule, and data will be gathered when the rocket is launched.

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